

# Thermal Analysis of Barrier Coating Material (TBC) For Gas Turbine Blade

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**ABSTRACT:** The thermal barrier coating (TBC) material is used to protect the gas turbine blade from high temperature and pressure gas, corrosion, erosion and wear. The bare material which is used for blade may reduce its useful life while in servicing in severe hot combustion gases. The hot combustion gas may induce and increase the thermal stresses and abnormal deformation. In this work, the deformation and von-misses stresses are calculated for bare material and different coating material with appropriate thickness applied on bare material. The gas turbine blade material is Inconel-713, and its coating material is Yattia stabilized zirconia (YSZ), Aluminum oxide ( $Al_2O_3$ ) and lanthanum Hexaluminate (LHA). The deformation and von-misses stresses are calculated for non-coated Inconel-713 and 0.5 mm thickness coated of Yattia stabilized zirconia (YSZ), Aluminum oxide ( $Al_2O_3$ ) and lanthanum Hexaluminate (LHA) material. The Finite element method (FEM) is used to calculate the deformation and von-misses stresses for non-coated and different coating materials with 0.5 mm thickness. The comparison is carried out for non-coating and for various coating materials in terms of deformation and von-misses stresses in minimum and maximum temperature.

**KEYWORDS:** TBC; YSZ; LHA;  $Al_2O_3$ ; FEM; FEA; CAD; TGO; TC, BC

## I. INTRODUCTION

A turbine is a fluid flow machine that translates enthalpy of the operational agent, also preferred to as the thermodynamic agent (stream of exhaust gas) into mechanical work that effects in the turning round of the gas turbine rotor along with blade. The essential advantages of gas turbines contain possibility to develop more power at quite compact dimensions and less bare weight, quite high efficiency of the energy conversion procedure, simple design and high consistent of operation. Conversely, the disadvantages are elevated working temperatures of some components, complicated geometrical shapes of the components, e.g. blade, which creates the manufacturing procedure difficult, in addition to high operational speeds of rotors that implement the require to apply reduction gears, e.g. when turbine-power receivers show restricted rotational speeds. Gas turbines, designed for industrial firm, automobiles, off-seashore applications, power engineering systems, and aeronautical applications offer pretty high efficiency of 30 to 45%. That efficiency relies to a very high extent, on temperature of combustion gases at the turbine inlet. Nowadays, this temperature has risen by more than 450 K, which has effected in substantial improvement in overall efficiency offered by turbines and made it possible to achieve even superior coefficient of unit power. Particular consideration has been paid to boost anti-heat and creep resistance of turbine components, especially of the 1st stage blade. Application of connected cooling systems to compact turbines is connected with unwanted drop in the turbine efficiency. That is why advance improvement of the turbine blade manufacture engineering processes, intended at capabilities to increase temperature upstream the turbine, has been giving consideration on broadening heat-resistant coatings showing outstanding resistance to corrosive elevated-temperature combustion gas, small TC, and high steadiness of the material structure. The operational temperature of gas turbine blades can be sustained within the following periods, depending on structural materials to employ and cooling intensity:

- 1100 - 1200 K (when no committed cooling system is required)
- 1200 - 1300 K (when blade cooling system is required)
- 1300 K and above (when an extreme-cooling system and TBC material is required).

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Moreover, blades are covered with materials that permit to raise the blade working temperature. However, a highly complicated design and manufacturing processes increase the production costs. [1]

## II. RELATED WORK

### Identification of Problem:

“Multidisciplinary analysis of the operational temperature increase of turbine blades in Combustion engines by application of the ceramic thermal barrier coatings (TBC)”.

- 1) The above research paper is referred as a base paper in which the material for turbine blade used is Inconel-713. Thermal analysis was carried out for inconel-713 without coating and with coating of YSZ material.
- 2) Further scope of area in the above research paper was to study the effect of temperature on structure such as deformation and von-misses stresses are observed.

### Objective of the Study:

By using the same material i.e. Inconel-713, following outcome can be performed

#### Analysis 1:

- 1) Thermal temperature (Maximum or Minimum)
- 2) Deformation
- 3) Von-misses stresses

#### Analysis 2:

- 1) Thermal stress analysis of the gas turbine blade of Inconel-713 without coating.
- 2) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of  $Al_2O_3$  material.
- 3) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of Lanthanum Hexaluminate (LHA) coating and
- 4) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of Yttria Stabilized Zirconia (YSZ).

Comparisons of the results shall be done for the gas turbine blade of Inconel-713 for non coating and coating of thickness 0.5 mm. Coating materials shall be used are  $Al_2O_3$ , LHA and YSZ.

## III. EXPERIMENTAL RESULTS

THERMAL STRUCTURAL ANALYSIS (FINITE ELEMENT ANALYSIS) OF GAS TURBINE BLADE:

### CAD Modeling:

#### Blade without coating:

Chord Length of Blade = 39.2005 mm

Height of Blade = 40 mm

Trailing edge Thickness = 0.8mm

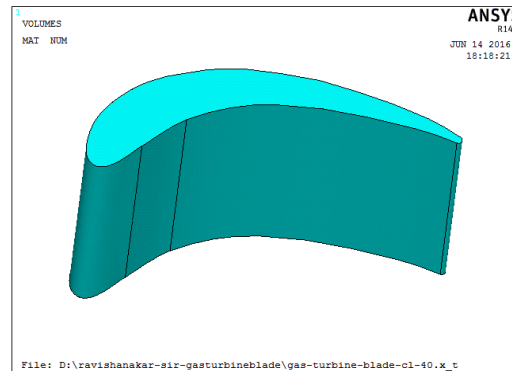
Leading edge Thickness = 2 mm

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**Fig.1. CAD Model of blade without coating**

### **Blade with coating (TBC) of thickness of 0.5 mm:**

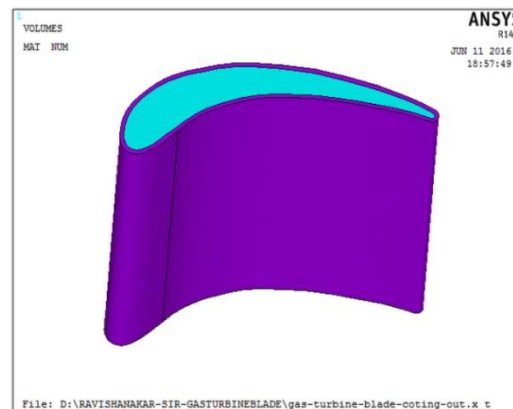
Chord Length of Blade = 39.2005 mm

Height of Blade = 40 mm

Trailing edge Thickness = 0.8mm

Leading edge Thickness = 2 mm

Coating Thickness (TBC) = 0.5 mm



**Fig. 2. CAD Model of blade with 0.5 mm thickness Coating (TBC)**

### **Mesh of blade without coating**

No. of Nodes = 3826

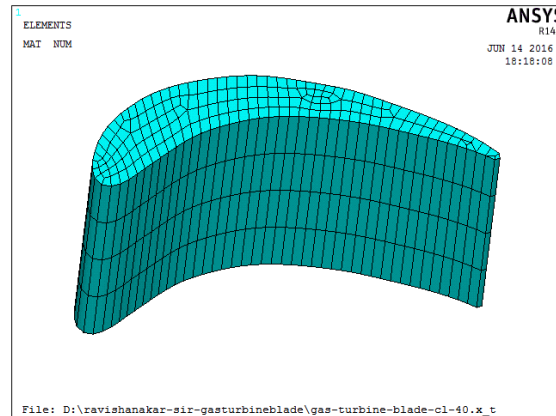
No. of Elements = 668

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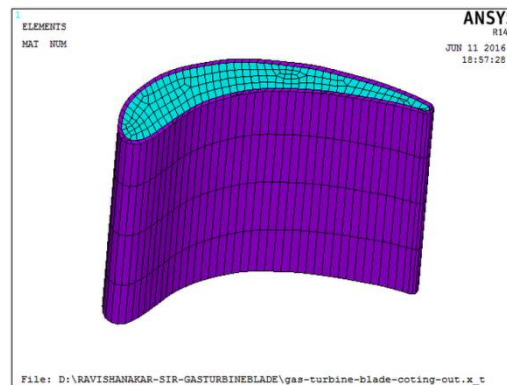


**Fig.3. Mesh of blade without coating**

Mesh of blade with 0.5 mm thickness of coating (TBC)

No. of Nodes = 5767

No. of Elements = 1112



**Fig.4. Mesh of blade with coating**

### Boundary condition:

The boundary condition is that the convection from hot gas at an average temperature of 864 °C. [6]

$h = 1000 \text{ W/m}^2\text{k}$

Temp.  $t = 864 \text{ °C}$

The convection at bottom at hub is

$h = 300 \text{ W/m}^2\text{k}$

Temp.  $t = 100 \text{ °C}$

The structural boundary condition fixed at bottom (hub)

$U_x = 0, U_y = 0, U_z = 0$

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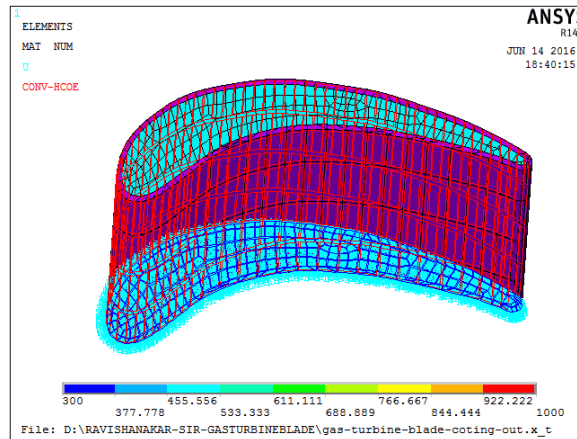


Fig.5. Boundary condition applied on Blade

**Result:**

**4.9. Comparison of Inconel-713, Inconel-713 and YSZ coating, Inconel-713 and Al<sub>2</sub>O<sub>3</sub> coating and Inconel-713 and LHA coating:**

The following table shows the Comparison of Inconel-713, inconel-713 and YSZ coating, inconel-713 and Al<sub>2</sub>O<sub>3</sub> coating and Inconel-713 and LHA coating:

Blade Material	Max temp °C	Min temp °C	Deformation in m	Von-misses-stress in N/m <sup>2</sup>	Nodes	Element
<b>Inconel-713</b>	847.758	741.292	4.17E-04	3.28E+09	3826	668
<b>Inconel-713 + YSZ coating</b>	820.472	686.289	3.53E-04	2.62E+09	5767	1112
<b>Inconel-713 + Al<sub>2</sub>O<sub>3</sub> coating</b>	819.702	714.519	3.58E-04	4.97E+09	5767	1112
<b>Inconel-713 + LHA coating</b>	824.665	702.541	3.81E-04	4.07E+09	5767	1112

Table no.1

The results clearly indicate the following,

- The Inconel-713 deformation is  $4.17 \times 10^{-4}$  m and Von-misses stress is  $3.28 \times 10^9$  N/m<sup>2</sup>.The maximum temperature is 847.758 °C and minimum temperature is 741.292 °C
- The Inconel-713 and 0.5 mm YSZ coating deformation is  $3.53 \times 10^{-4}$  m and Von-misses stress is  $2.62 \times 10^9$  N/m<sup>2</sup>. The maximum temperature is 820.472 °C and minimum temperature is 686.289 °C
- The Inconel-713 and 0.5 mm Al<sub>2</sub>O<sub>3</sub> coating deformation is  $3.58 \times 10^{-4}$  m and Von-misses stress is  $4.97 \times 10^9$  N/m<sup>2</sup>. The maximum temperature is 819.702 °C and minimum temperature is 714.519 °C
- The Inconel-713 and 0.5 mm LHA coating deformation is  $3.81 \times 10^{-4}$  m and Von-misses stress is  $4.07 \times 10^9$  N/m<sup>2</sup>. The maximum temperature is 824.665 °C and minimum temperature is 702.541 °C

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## IV. CONCLUSION

The comparison of Inconel-713 (without coating) and coating (0.5 mm) of different material such as YSZ (Yttria Stabilized Zirconia),  $Al_2O_3$  (aluminum oxide) and LHA (Lanthanum Hexaluminum) as shown in the above table. From the above comparison, it is found that YSZ coating has minimum deformation and minimum Von-mises stress as compared to  $Al_2O_3$  coating and LHA coating.

### Future Scope of work:

- To improve the obtained results, further in future; one can increase the coating thickness from 0.5 mm to 1 mm or 2 mm by which von-mises stresses and deformation may reduce considerably.
- By providing the holes axially in the blade, may also reduce the temperature of the blade thereby increase the cooling effect which in turn reduces the von-mises stresses and deformation.

## REFERENCES

- [1] Józef Blachnio and Wojciech Izydor Pawlak (2011). Damageability of Gas Turbine Blades – Evaluation of Exhaust Gas Temperature in Front of the Turbine Using a Non-Linear Observer, *Advances in Gas Turbine Technology*.
- [2] Cyrus B. Meher Homji, Bechtel Corporation, Houston, Texas and George Gabriles, G & B consultant, Texas. Gas turbine blade failure-Causes, Avoidance and Trouble shooting.
- [3] Sair Eshati, School of Engineering, Cranfield University, Abdullahi Abu, Panagiotis Laskaridis, Anthony Haslam, UK (2011). Investigation into the Effects of Operating Conditions and Design Parameters on the Creep Life of High Pressure Turbine Blades in a Stationary Gas Turbine Engine.
- [4] E. Marathoniti, N. Vourdas, Georgiopoulos, O-D. Trusca, Trusca. Andreouli, V.N. Stathopoulos, Development of  $LaAlO_3$ -based thermal barrier coatings by solution precursor thermal spray.
- [5] David R. Clarke, Matthias Oechsner, and Nitin P. Padture, Guest Editors, (2012), Thermal-barrier coatings for more efficient gas-turbine engines.
- [6] T. Sadowski, P. Golewski, (2010), Multidisciplinary analysis of the operational temperature increase of turbine blade in combustion engines by application of the ceramic thermal barrier coatings (TBC). *Nadbystrzycka 40 Str., 20-618*.
- [7] Michael W. Reedy a,b, Timothy J. Eden a, John K. Potter a, Douglas E. Wolfe a,c, (2011) Erosion performance and characterization of nanolayer (Ti,Cr)N hard coatings for gas turbine engine compressor blade applications, 119 Materials Research Building, University Park, PA 16802.
- [8] R. Rajendran, M.D. Ganeshachar, Jivankumar, T. Mohana Rao, (2011), Condition assessment of gas turbine blades and coatings.
- [9] M.H. Vidal-Setif, N. Chellah, C. Rio, C. Sanchez, O. Lavigne, (2012) Calcium-magnesium-alumino-silicate (CMAS) degradation of EB-PVD thermal barrier coatings: Characterization of CMAS damage on ex-service high pressure blade TBCs, ONERA, the French Aerospace Lab, 92322 Châtillon, France.
- [10] W. Zhu a,b, M. Cai a,b, L. Yanga,c, J.W. Guod, Y.C. Zhou, C. Lue, (2015), The effect of morphology of thermally grown oxide on the stress field in a turbine blade with thermal barrier coatings.
- [11] Son Thanh Nguyen, Tadachika Nakayama, Hisayuki Suematsu, Tsuneo Suzuki, Masatoshi Takeda, Koichi Niihara, (2016). Low thermal conductivity  $Y_2Ti_2O_7$  as a candidate material for thermal / environmental barrier coatings. Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan.
- [12] N. Asok Kumar, S.R. Kale, (2002), Numerical simulation of steady state heat transfer in a ceramic-coated gas turbine blade.
- [13] R. Vilar, E.C. Santos, P.N. Ferreira, N. Franco, R.C. da Silva, (2009), Structure of NiCrAlY coatings deposited on single-crystal alloy turbine blade material by laser cladding. Instituto Tecnológico e Nuclear, Estrada Nacional 10, 2685 Sacave m, Portugal.
- [14] Jaroslav Pokluda, Marta Kianicova, (2010), Assessment of performance capability of turbine blades with protective coatings after overheating events.
- [15] In Hwan Shina, et al, (2013), Assessment of the characteristics of thermal barrier coating applied to Gas turbine blade by thermo-gradient mechanical test.
- [16] L. Yang, Q.X. Liu, Y.C. Zhou, W.G. Mao, C. Lu, (2014), Finite Element Simulation on Thermal Fatigue of a Turbine Blade with Thermal Barrier Coatings.
- [17] Sijie Yana, Dahu Zhub, Kejia Zhuanga, Xiaoming Zhanga, Han Ding (2014), Modeling and analysis of coated tool temperature variation in dry milling of Inconel -718 turbine blade considering flank wear effect.
- [18] J.R. Laguna-Camacho a, L.Y. Villagrán-Villegas et al, (2015), A study of the wear damage on gas turbine blades. C.P. 93390, Poza Rica, Veracruz, Mexico.
- [19] H.M. Tawancy, A.I. Mohammad, L.M. Al-Hadhrani, H. Dafalla, F.K. Alyousf, (2015), On the performance and failure mechanism of thermal barrier coating systems used in gas turbine blade applications: Influence of bond coat/superalloy combination.
- [20] W. Zhu, M. Cai et al, (2015), The effect of morphology of thermally grown oxide on the stress field in a turbine blade with thermal barrier coatings.
- [21] Jolanta Baran, (2016), Redesign of steam turbine rotor blades and rotor packages Environmental analysis within systematic eco-design approach. Roosevelta 26, 41-800 Zabrze, Poland.

## International Journal of Innovative Research in Science, Engineering and Technology

*(A High Impact Factor & UGC Approved Journal)*

Website: [www.ijirset.com](http://www.ijirset.com)

**Vol. 6, Issue 8, August 2017**

- [22] Mahdi Bozorg, Nezhad-Nobijari at all,(2016), Evaluation of the aluminide coating on cleaned internal passages of used gas turbine blades.
- [23] Ketui Daniel, Chi Feng , Shan Gao ,(2016), Single wavelength and ratio pyrometry reflection errors in temperature measurement of gas turbine blade. School of Information and Communication Engineering, No. 145-1, Nantong Street, Harbin 150001, China.
- [24] W.Z. Tang, L. Yang at all, (2016), Numerical Simulation of Temperature Distribution and Thermal- Stress Field in a Turbine Blade with Multilayer-Structure TBCs by a Fluid–Solid Coupling Method.
- [25] Mazaheri, Zeinalpour, Bokaei, (2016), Turbine Blade Cooling Passages Optimization Using Reduced Conjugate Heat Transfer methodology.